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Structure formation on the surface of alloys irradiated by femtosecond laser pulses

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ABSTRACT

Laser-induced periodic surface structures with different spatial characteristics have been observed after multiple linearly polarized femtosecond laser pulse (120 fs, 800 nm, 1 Hz to 1 kHz pulse repetition frequency) irradiation on alloys. With the increasing number of pulses, nanoripples, classical ripples and modulation ripples with a period close to half of classical ripples have all been induced. The generation of second-harmonic has been supposed to be the main mechanism in the formation of modulation ripples.

1. Introduction

Since the early observation of ripples or laser-induced periodic surface structures (LIPSSs) on semiconductors by Birnbaum, such structures have been studied extensively in the past [1–4]. The wide range of applications has been found in enhancing light absorption, efficient terahertz radiation generation, and hydrophilic properties. Recently, femtosecond lasers have been introduced as a powerful "tool" to generate LIPSSs on most materials: dielectrics, semiconductors and metals [5–14]. In order to identify the physical origin of LIPSSs, different predictions have been made in the past in which the period of the LIPSSs was supposedly depends on the properties of material and the irradiation parameters. Classic ripples (CRs, low spatial frequency LIPSSs, LSFL) usually exhibit the characteristic period close to the laser wavelength of the incident radiation and orientation perpendicular to the polarization direction of the incident laser. The mechanism is generally accepted based on the assumption of the interference of the incident laser beam with surface wave generated by scattering of laser radiation from surface roughness [2–4]. However, the subwavelength ripples also called nanoripples (high spatial frequency LIPSS, HSFL) have been recently observed in the transparent solids, semiconductors and metals [9–14]. The transition from the LSFL features toward the formation of HSFL has been studied on ZnO arising from different laser fluences [11]. The nature of nanoripples is still controversially discussed and very different mechanisms have been proposed such as interference effects [8], second-harmonic generation (SHG) [7,12,13], excitation of surface plasmon polaritons [14], and self-organization [5].

In this paper, we carried out ablation experiments on alloys. Not only did we observed the CR induced by the femtosecond laser pulse, but also achieved the nanoripples on the ablated areas and modulation ripple (MR) formed at the middle of each ridge of the CR. The SHG in the sample surface excited by the incident laser is supposed to be the main mechanism in the formation of modulation ripples.

2. Experiments

The materials used in the experiment were Zr-based amorphous alloy foils, whose composition (at.%) is: Zr62, Cu18, Ni10, Al10. Amorphous alloys have always been optimized candidates because of their mechanically isotropic and structurally homo-

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geneous properties. Amorphous alloys are assumed to be free from size effects and structural defects, and have been a promising material for micro-electro-mechanical systems. The samples were prepared as foils with thickness of 50 μm.

A Ti:sapphire regenerative amplified laser system (Coherent Inc) with pulse width of 120 fs, wavelength of 800 nm and repetition rate of 1 Hz to 1 kHz was used as the irradiation source in our experiments. The sample was mounted on an electric XYZ-translation stage. The linearly polarized Gaussian laser beam was focused onto the surface of the sample by using an optical microscope (LMPLFL 5x/0.15, Nikon) at a normal incidence angle. After passing through a variable neutral-density filter to adjust the irradiation energy, a mechanical shutter was used to select the number of laser pulses imposed per site on sample surface. The laser writing processes were monitored in real time by a charge coupled device (CCD) monitor through the optical microscope. All experiments were performed in an ambient air condition under atmospheric pressure. Before and after the laser processing, the sample was cleaned by an ultrasonic cleaner. After irradiation, the surface morphology was characterized by a scanning electron microscope (SEM, Hitachi S-4800).

3. Results and discussions

Fig. 1 shows SEM images of the laser irradiated surfaces. In order to investigate the pulse to pulse development of the surface structures, we performed a pulse number dependent measurement of the LIPSSs period with the same pulse energy of 0.3 μJ but different number of laser pulse. Fig. 1(a) shows the SEM image of the ablation spot irradiated by 3 pulses. It is obvious that the nanoripples with the periodicity about 200 nm and orientation parallel to the polarization of the laser radiation cover the ablated area. The selected region in Fig. 1(a) is magnified in Fig. 1(b). Most of the nanoripples reported recently were oriented perpendicular to the direction of laser polarization. The phenomenon of nanoripples oriented parallel to the polarization of laser has also been reported on 6H–SiC crystal [10], diamond [8] and ZnSe crystal [12] after irradiation by linearly polarized femtosecond laser pulses. By far, the main causes of the distinct polarization dependence of ripple orientation are still ambiguous. The different properties of material may be involved in the origin. Moreover, previous studies showed that ripples could be induced with a single laser pulse [3,4]. But we note here that LIPSSs have not been detected in our experiments for single pulse of laser irradiation at

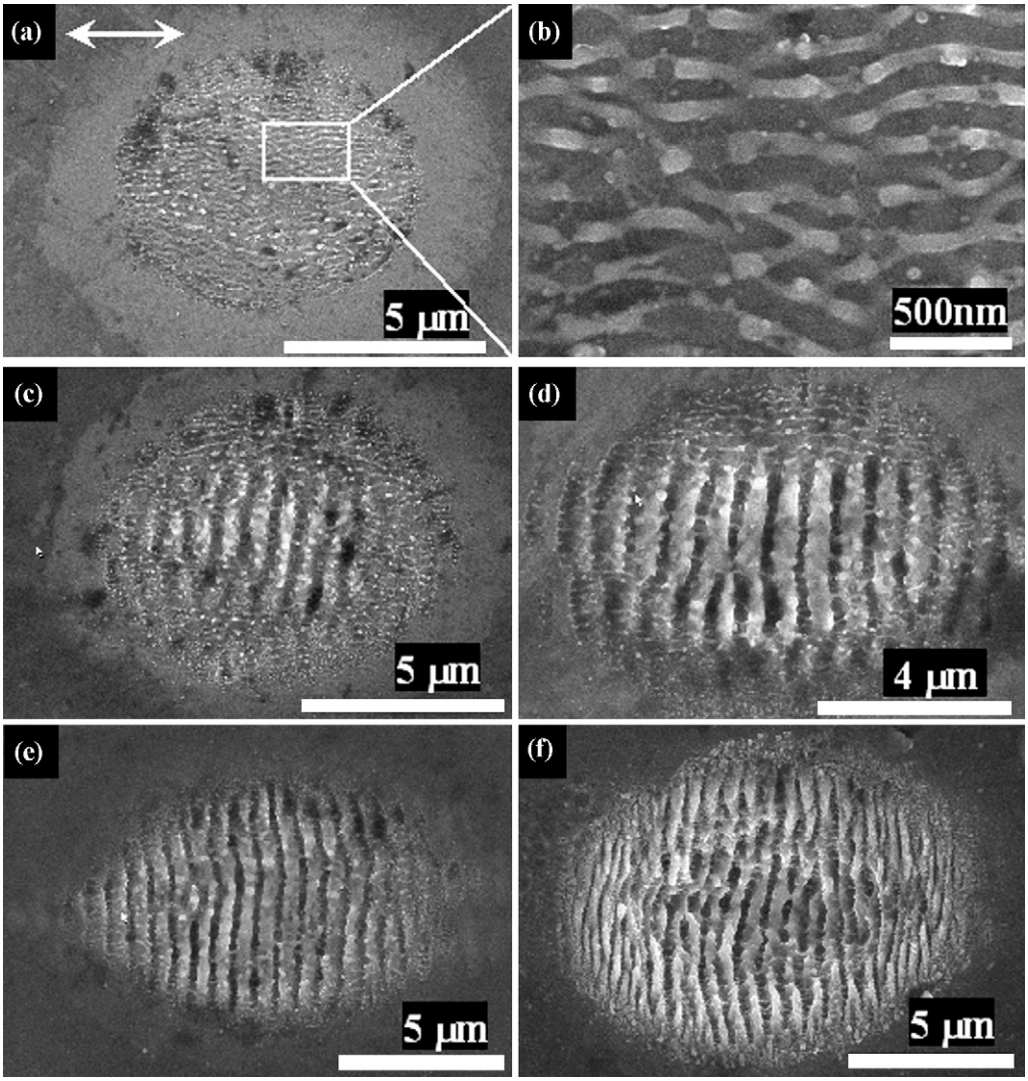

Fig. 1. SEM images of LIPSSs on alloys induced by 800 nm with a pulse energy of 0.3 μJ and varied pulse numbers. (a) 3 pulses, (b) depict magnified image of areas in (a); (c) 6 pulses, (d) 8 pulses, (e) 20 pulses, (f) 100 pulses. The repetition rate corresponding to (a–d) and (e and f) are 1 Hz and 10 Hz, respectively. The orientation of polarization of the irradiated laser is indicated by an arrow.